U. S. DEPARTMENT OF AGRICULTURE

FOREST SERVICE

ALTA AVALANCHE STUDY CENTER

WASATCH NATIONAL FOREST

TRANSLATION NO. 10

METHOD OF PREDICTING AVALANCHE DANGER FROM SNOWFALL INTENSITY IN THE TIEN-SHAN

By M. P. SHCHERBAKOV

Sposob prognoza lavinnoi opasnosti po intensivnosti snegopadov na Tian' - Shane. Akademiia Nauk SSSR, Izvestiia, Ser. Geogr., No. 3:100-111, May/June 1966.

Translated by R. I. Perla
Avalanche Hazard Forecaster

September 1969

It has been known for a long time that avalanche formation is caused by unstable snow conditions on the slope in consequence of overload or the weakening of internal bonds. Zdarsky (1929), Seligman (1936), and Flaig (1955) have written about this. Tyshinskii and others (1949, 1953) have thoroughly discussed this point. The original inhabitants of the Alps, Himalayas, Andes, Caucasus, Altai, Tien-Shan, and other mountain regions were acquainted with the most significant signs of an avalanche hazard such as a heavy snowfall or blizzard, an intense thaw, the appearance of dangerous snow stratigraphy, the formation of cracks in the snow, etc. However, all of these signs are only qualitative estimates of the avalanche hazard. For a quantitative expression of the avalanche hazard, different authors have used relationships for the internal characteristics of the snow. Their results were dependent on specific types of avalanches, peculiarities of the snow cover, and the methods of the study. The majority of the investigators has expressed the avalanche hazard in terms of a comparison of the actual strength of the snow cover with its critical value computed according to a particular formula. Generally, the variables of these formulae are: the critical thickness of the snow cover, the steepness of the slope, the physical-mechanical properties of the snow, the coefficients of friction, and sometimes the dimensions of the snow slab.

G. G. Saatchan (1936), for example cites the following dependence

$$h = \frac{c/\gamma}{\sin\alpha - f\cos\alpha - n/\gamma l} \qquad (1)$$

where γ is the snow density (kg m^{-3})

h is the height of the snow cover (m)

c is the bonding strength of the snow (kg m^{-2})

n is the tensile strength of the snow (kg m^{-2})

f is the coefficient of friction

α is the slope angle (deg.)

l is the length of the slab (m)

Holding c, n, and γ constant for a given type of snow and taking $l = 100$ m., Saatchan constructed a series of equilibrium curves for the snow cover.

The difficulty of this method is that it requires a measurement of the slab length, which is practically impossible to obtain before the slab releases, and that it does not account for the wide variation in the mechanical properties of the same types of snow (Shcherbakov 1962). According to the results of Saatchan, the critical thickness of the freshly fallen snow may vary between 0.5 and 8 meters--this cannot be reliable.

G. K. Sulakvelidze (1955) assuming snow to be a rigid and elastic substance, arrived at the following formula for the equilibrium of old compressed snow

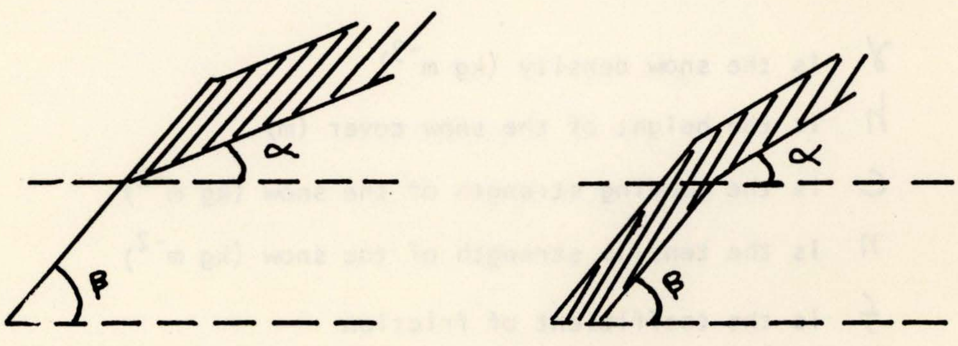
$$h_k = \frac{C_3 T l}{\gamma l T \sin\alpha - f \gamma T \cos\alpha - C_1 T - 2 C_2 l} \quad (2)$$

where T and l are geometrical dimensions of the snow slab.

f is the coefficient of internal friction.

C_1 , C_2 , and C_3 are components of bonding strength.

For freshly precipitated dry snow, D. N. Gongadze (1954, 1955) proposed equilibrium formulae for two forms of topography: "ledge terrain" and "inflected terrain" (see Translator's Diag.).



TRANSLATOR'S DIAGRAMS FOR GONGADZE'S FORMULAE
(Reference: Gongadze 1954)

For ledge terrain the formula is

$$h_K = \frac{2C}{\gamma} \frac{\sin\omega \cos\phi}{\sin^2 \frac{\omega+\alpha-\phi}{2}} \qquad (3)$$

and for inflected terrain

$$h_K = \frac{2C}{\gamma} \frac{\cos\phi \cos\frac{\beta-\alpha}{2}}{\sin^2\left(\frac{90-\phi}{2}+\frac{\alpha+\beta}{4}\right)} \qquad (4)$$

where ϕ is the angle of internal friction, $\omega = \beta - \alpha$.

B. S. Chitadze (1961) derived formulae for the equilibrium of ledge terrain in the form of a prism and a trapezoid. For the prismatic form

$$h_K = \frac{2C}{\rho g} \frac{\cos\phi}{\sin(\alpha-\phi)} \qquad (5)$$

and for the trapezoidal form

$$h_K = \frac{CT \cos\phi}{\rho g d \sin(\alpha-\phi)} \qquad (6)$$

where α is the inclination of the slip surface

ρ is the density

g is the gravitational acceleration

T and d are geometrical dimensions of the ledge.

Utilizing Equation 2, A. G. Balabuyev and G. K. Sulakvelidze (1947) constructed avalanche diagrams from which it is possible to determine the slope angle, the avalanche hazard for a given type of snow, and the critical thickness of the newly fallen snow.

K. S. Losev (1960) proposed a method for calculating the time of onset of the avalanche hazard for freshly fallen and wind transferred snow by dividing the critical thickness of the snow cover by the rate of accumulation. Although his method is correct in principle, it is practically impossible to measure the physical-mechanical properties of snow in the release zone that are required in his formula for critical thickness. It may be worthwhile to simplify Losev's approach by introducing empirical relationships for each avalanche-threatened region; however, such relationships are not cited by Losev.

All of the above methods for determining the avalanche hazard according to formulae for the critical thickness of the snow are based on special conditions and are therefore only applicable when these conditions apply. In our view, their chief shortcomings are: they do not predict <u>when</u> the snow cover reaches its critical value, and that they require inaccessible measurements to be made in the avalanche release zone of physical-mechanical properties and slab dimensions. Therefore, the practical application of all of these relationships becomes extremely inconvenient.

Other authors (Krasnosel'skii, 1963; Moskalev, 1963) relate empirically the avalanche hazard with the physical-mechanical properties of the snow. E. B. Krasnosel'skii assumes that the instability of a slab depends on the ratio of the shear stress (f_{cK}) to the shear strength (f_c) of the underlying surface of the slab

$$K_{\Lambda 0} = \frac{f_{cK}}{f_c} \qquad (7)$$

where $K_{\Lambda 0}$ is the coefficient of the avalanche hazard and for

$K_{\Lambda 0} < 1$ the avalanche hazard is absent; for $K_{\Lambda 0} \approx 1$

avalanches may be induced artificially; for dry snow $1 \leq K_{\Lambda 0} \leq 2$.

indicates an avalanche danger in winter months; for wet snow

$2 \leq K_{\Lambda 0} \leq 3$ indicates an avalanche danger in spring months.

Krasnosel'skii appears to make a series of questionable assumptions in order to equate basal and periphery effects. He assumes that the shear strength is comparable to the tensile strength and furthermore, for a slab thickness (h) and a semi-circular slab of radius (R), the basal area is $\pi R^2/2$ and the periphery area is $\pi R h$. Only by equating the basal and periphery effects is he able to relate (7) to slab stability. The role of the periphery failure, as observations indicate, is insignificantly small in comparison to the basal failure; in those cases when the formation of cracks precedes the slab release, it is generally reduced to zero.

The real insufficiency of Krasnosel'skii's method rests on the impossibility of predicting changes even in the immediate future for shear stress and strength. Although a measure of the margin of the shear strength over the shear stress may be a present indication of the hazard, it is not a forecast. Nonetheless, the proposed coefficient may be used in practice as an index of appropriateness for artificially releasing avalanches by means of explosives (Maximov and Krasnosel'skii, 1964).

Yu. D. Moskalev (1963) came to the conclusion that the avalanche danger for a given slope angle depends on the ratio between the bonding strength and the water content of the snow (c/w) and also on its coefficient of internal friction. From this he proposed a calculation of slab stability from a special nomogram and the avalanche danger from a chart of isolines based on snow and meteorological parameters. However, in order to determine the avalanche hazard it is necessary to measure c/w as well as the coefficients of viscosity on the avalanche-threatened slopes. Therefore, the method of Moskalev also requires measurements to be made with increasing frequency in the avalanche release zone during periods of high hazard to the observers.

The most promising alternative for relating the avalanche hazard to meteorological factors and the experimental properties of the snow involves forecasting according to the amount of snow transported by wind (Akkouratov, 1956). From many years of observation in the Khibiny, V. N. Akkouratov came to the conclusion that the majority of avalanches in that region resulted from wind drifting. Knowing the measured amount of snow transport (gm $cm^{-2}min^{-1}$) it is possible to find the times of onset and termination of the hazard on a specially prepared avalanche diagram. The corresponding formulae are

$$t_1 = \frac{m + 38}{m + 2} \quad (8)$$

$$t_2 = \frac{6.8m + 95}{m - 1.86} \quad (9)$$

where t_1 is the beginning of the avalanche hazard

t_2 is the termination of the avalanche hazard

and m is the snow transport by wind (gm $cm^{-2}min^{-1}$)

Because this method is simple, reliable (as justified in practice), and indeed a method of predicting the future conditions, we prefer such an approach for forecasting various types of avalanches in certain regions.

Relatively recently, K. L. Abdushelishvili and V. Sh. Tsomaia (1963) proposed a method of forecasting avalanches in the Caucasus which emphasized variations in the relative humidity of the air. As in the method of V. N. Akkouratov, the authors emphasized the empirical aspects of the problem. From their observations, the avalanche hazard almost always arises when the relative humidity attains a steady value of 75%. In order to determine the time of descent of avalanches of freshly fallen snow, they assumed that the critical amount of deposition depends on the thickness of the old snow layer at the moment the relative humidity attains 75%. The authors prepared avalanche forecasts based on the weather forecasts of expected deposition. They established the following empirical dependence for the critical deposition as a function of the thickness of the old snow layer when the relative humidity attains 75%

$$X_n = 55 - 2.8\sqrt{h_{75}} \quad (10)$$

where X_n is the total deposition necessary for avalanches of freshly fallen snow and h_{75} is the thickness of the old snow layer on the day before the mean daily relative humidity attains 75%.

It is doubtful that this can be considered a fundamental method of forecasting avalanches. In the first place why should the relative humidity be a dependable indication of the avalanche hazard? The data cited by the authors on a graph of avalanche conditions in the winter 1960/61 in the region of Krestov Pass show that the moisture of the air attained 75% on 18 occasions; however, in only four cases did avalanches descend. Results of observations from

four avalanche stations in the Kirgiz showed that snow did not fall on scores of occasions when the relative humidity achieved 75%, 80%, and even 90%. Thus, the cited relationship between the critical value of total deposition and old snow thickness is questionable and may have been derived by chance; observations in the Kirgiz do not detect such a relationship. Finally, it is incomprehensible how a weather forecast which can neither predict the intensity of the snowfall nor the expected total deposition can possibly determine the date of the critical deposition.

Thus, a short survey of the existing methods for determining and forecasting the avalanche hazard shows that Akkouratov's scheme of forecasting by wind transport is the most reliable and accessible. This method has almost completely solved the forecast problem in the Khibiny where 80% of all avalanches is caused by wind transport. The problem of avalanche forecasting for other regions in the Soviet Region is still not solved.

According to our observations in the Kirgiz (1965), 60% of all avalanches is directly related to newly fallen snow and 80 to 85% is directly or indirectly related to periods of snowfall. Unfortunately, the method of Akkouratov is of limited use in the Kirgiz since wind transport accounts for only 10 to 13% of the total. Therefore, the first task of avalanche science in the Kirgiz is to develop methods for forecasting avalanches of freshly fallen snow. This present paper describes a method of avalanche forecasting from snowfall intensity developed by the author and based on observations from four avalanche stations in the Kirgiz over the period 1958 to 1964.

M. I. Iveronova (1953, 1962) has repeatedly pointed out the role of snowfall intensity in avalanche formation at the crest of the Terskei- Ala-Too in the Tien-Shan. Observations conducted by us in the Tien-Shan and Altai confirmed this idea and an attempt was made to establish a quantitative dependence between snowfall intensity and the time of onset of the avalanche hazard.

The following simple equation has been customary for the computation of snow slope stability

$$F_{ck} S = cS + nS_1 \qquad (11)$$

where F_{ck} is the tangential component of force exerted by one square meter of the slab (kg m^{-2}), C is the shear strength of the snow (kg-m^{-2}), S is the area of the base of the slab (m^2), n is the

tensile strength of the snow, and S_1 is the area of periphery fracture.

From observations, S is 100 to 150 times as large as S_1 so that in the majority of cases nS_1 is only 1% of CS and therefore the periphery effect is insignificantly small in comparison to the basal effect. Consequently, neglecting nS_1 and incorporating static friction in the experimental measurement of C, Equation (11) acquires the form

$$F_{ck} = C \tag{12}$$

As we have shown previously (1962), the shear strength of newly fallen snow is related to snow density (d) and slab thickness (h) by the following

$$C = 3(dh)^2 + 1.4dh + 8.7 \tag{13}$$

Furthermore, for a slope angle (α), we substitute into Equation (12)

$$C = 3\left(\frac{dh}{\cos\alpha}\right)^2 + 1.4\frac{dh}{\cos\alpha} + 8.7$$

$$F_{ck} = 10 dh \sin\alpha$$

and obtain the following formula for the critical thickness of a slab of freshly fallen snow

$$h = \left[\left(\frac{\cos\alpha - 3.6\sin\alpha\cos^2\alpha}{4.3d}\right)^2 + \frac{2.9\cos^2\alpha}{d^2}\right]^{1/2} + \frac{\cos\alpha - 3.6\sin\alpha\cos^2\alpha}{4.3d} \tag{14}$$

The graphical dependence of h as a function of α for d = 1 is shown in Figure 1.

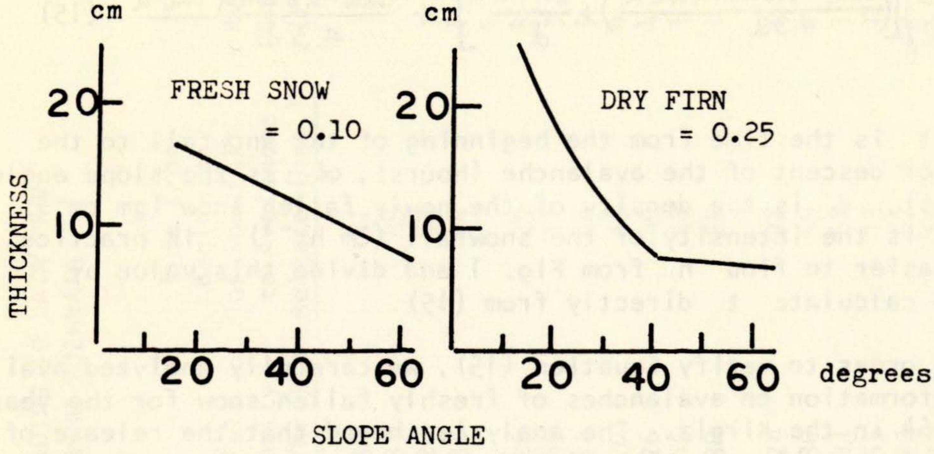


Fig. 1 Critical thickness of snow versus slope angle.

For a given snowfall intensity (δ), which we assume constant throughout the storm, we can determine the time when the thickness of the freshly fallen snow achieves its critical value

$$t=\frac{h}{\delta}=\frac{1}{\delta}\left\{\left[\left(\frac{\cos\alpha-3.6\sin\alpha\cos^2\alpha}{4.3d}\right)^2+\frac{2.9\cos^2\alpha}{d^2}\right]^{1/2}+\frac{\cos\alpha-3.6\sin\alpha\cos^2\alpha}{4.3d}\right. \qquad (15)$$

where t is the time from the beginning of the snowfall to the moment of descent of the avalanche (hours), α is the slope angle (degrees), d is the density of the newly fallen snow (gm cm^{-3}), and δ is the intensity of the snowfall (cm hr^{-1}). In practice, it is easier to find h from Fig. 1 and divide this value by δ than to calculate t directly from (15).

In order to verify Equation (15), we carefully analyzed available information on avalanches of freshly fallen snow for the years 1958-1964 in the Kirgiz. The analysis showed that the release of such avalanches is closely related to the water content of the snow, the thickness of the freshly fallen snow, and the duration and intensity of the snowfall (Table 1).

TABLE I

RELATIONSHIP OF AVALANCHE CONDITIONS ACCORDING TO DATA FROM THE SNOW AVALANCHE STATION, TYUIA - ASHU YUZHNAIA

Winter	Duration of Snowfall (hrs.)	Amount of Deposition (mm. of H_2O)	Amount of New Snow (cm.)	Snowfall Intensity (cm./hr.)	Time from Beginning of Snowfall to Avalanche Release (hrs.)	Avalanche Group No. (Fig. 4.)
	69	16	25	0,36	41	4
	38	10	12	0,33	45	4
1958-1959	53	12	11	0,20	53	
	66	30	25	0,38	34	1 3 4 5 6
	36	6	13	0,36	29	3 4
	22	6	10	0,45	11	3 4
	44	3	6	0,14	44	3 6
	16	5	11	0,70	16	4 3
1959-1960	49	23	13	0,26	49	4 5
	48	27	22	0,46	38	1 4 2
	62	23	19	0,30	58	1 3 4 2
	78	19	19	0,24	78	1
	69	18	20	0,30	49	1 4 6
1960-1961	63	25	26	0,41	68	3
	22	12	12	0,55	13	1 4
	70	20	21	0,30	62	2 4
	55	9	7	0,13	46	4
	65	10	11	0,17	65	1 4

Table I - continued

Winter	Duration of Snowfall (hrs.)	Amount of Deposition (mm. of H_2O)	Amount of New Snow (cm.)	Snowfall Intensity (cm./hr.)	Time from Beginning of Snowfall to Avalanche Release (hrs.)	Avalanche Group No. (Fig. 4.)
1961-1962	56	10	15	0,27	48	4
	79	27	30	0,42	51	3 4
	24	20	26	1,08	6	4
	66	12	11	0,16	57	4 6
	21	10	10	0,48	26	3
	42	9	12	0,29	35	1
1962-1963	41	10	7	0,17	41	4
	67	12	10	0,15	57	1
	14	8	7	0,50	12	1 5
	55	12	12	0,22	50	1
	32	7	7	0,22	48	1 6
	14	3	8	0,57	13	2 4
1963-1964	52	13	20	0,40	38	1
	88	18	39	0,44	60	4 5
	106	16	18	0,17	82	1 4 5
	39	10	11	0,28	37	2 6a
	51	12	14	0,28	55	4 1 2 4 6 6a
	29	15	15	0,51	26	1 4
	64	19	22	0,35	40	1
	34	14	15	0,45	33	1 2
	71	20	20	0,27	71	1
	40	14	14	0,37	40	1
	41	21	10	0,24	41	1

In Figure 2 the intensity of snowfall is plotted as a function of the time of avalanche release.

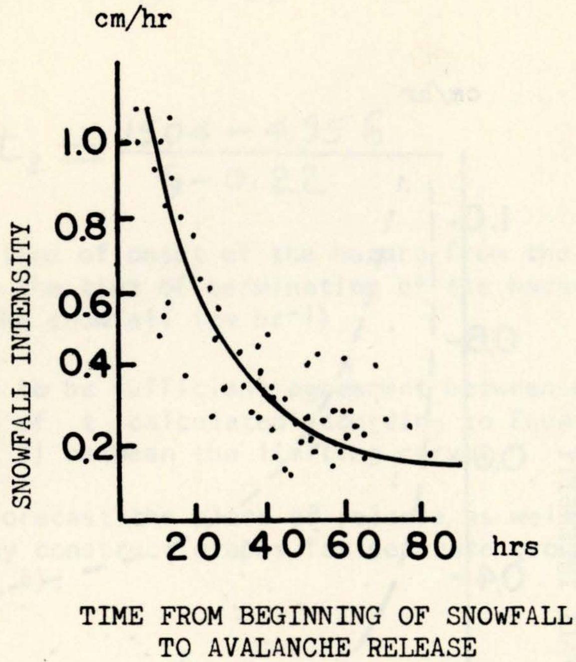


Fig. 2 Time to release of avalanche versus snowfall intensity.

Although the diverse conditions of the storms and the geomorphological differences of the slopes produce a scatter in the data, nonetheless, it is possible to determine limiting curves for the period of avalanche danger (Fig. 3).

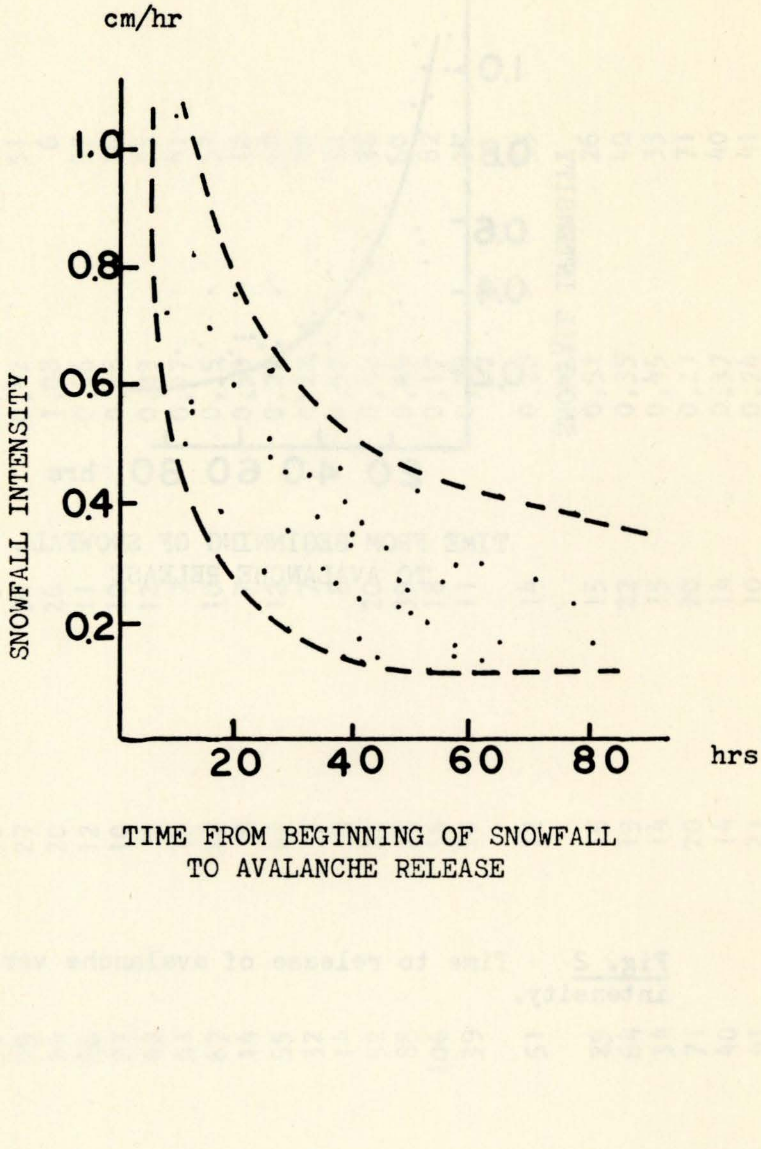


Fig. 3 Avalanche danger period for the region of the snow avalanche station, Tyuia-Ashu Yuzhnaia.

The following empirical relationships fit these curves

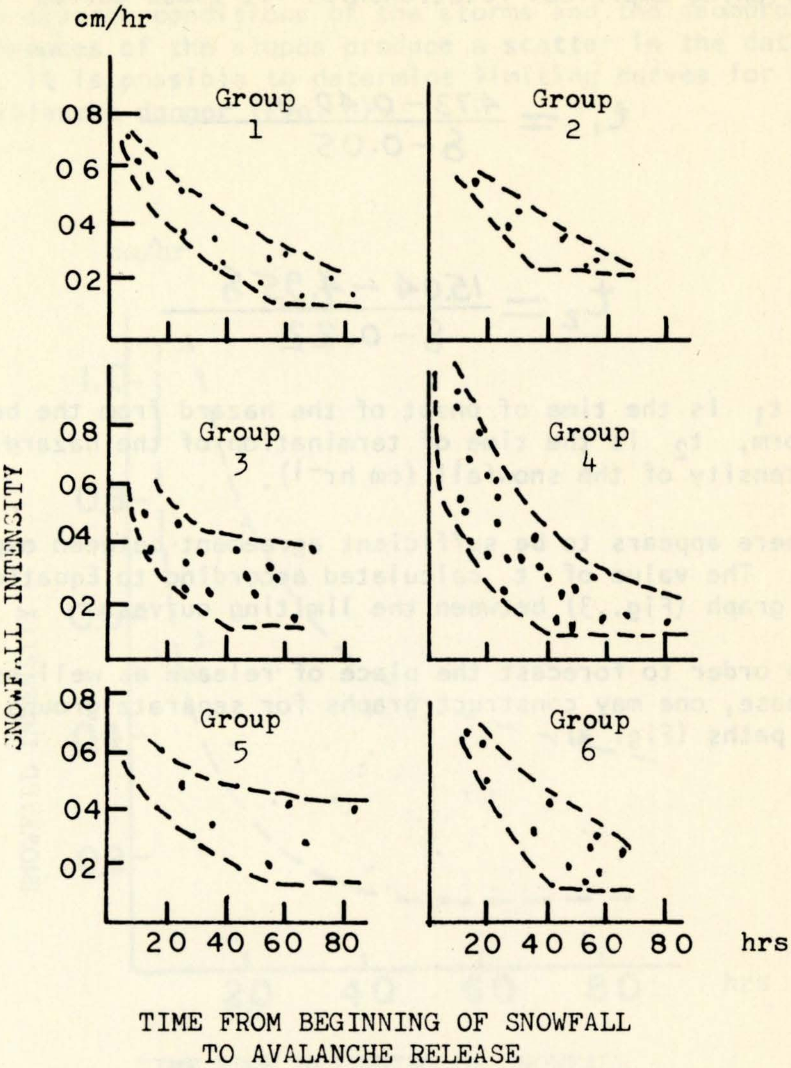
$$t_1 = \frac{4.73 - 0.40\,\delta}{\delta - 0.05} \tag{16}$$

$$t_2 = \frac{15.04 - 4.95\,\delta}{\delta - 0.22} \tag{17}$$

where t_1 is the time of onset of the hazard from the beginning of the storm, t_2 is the time of termination of the hazard, and δ is the intensity of the snowfall (cm hr^{-1}).

There appears to be sufficient agreement between experiment and theory. The value of t calculated according to Equation (15) lies on the graph (Fig. 3) between the limiting curves.

In order to forecast the place of release as well as the time of release, one may construct graphs for separate groups of avalanche paths (Fig. 4).



<u>Fig. 4</u> Avalanche danger period for various paths in the region of the snow avalanche station, Tyuia-Ashu Yuzhnaia.

Since in each avalanche region, t as a function of δ has its own peculiarity, the corresponding empirical dependence will vary somewhat from the general case. Each dependence can be established from a sufficient amount of observations. Presently, a large portion of the Kirgiz is not under avalanche surveillance so that a computational formula is not initially feasible.

While using the proposed method one should take into account, firstly, the snowfall may cease before the avalanche period begins, and secondly, it may vary considerably in its intensity. Therefore, it is necessary to keep track of the snowfall intensity and insert corrections for determining the amount of time to the beginning of the hazard. Having verified that the snowfall intensity is sufficiently intense and steady, it is possible to prepare a forecast either according to the graph or the formula. Only further developments and improvements in forecasting the intensity and duration of the expected snowfall will permit the avalanche forecast to look further ahead into time.

In addition to forecasting the time and place of avalanches of freshly fallen snow, it is possible to estimate limits for the volume of snow which will be released. From observations: the larger the intensity of the deposition, the larger the peak volume of any one avalanche and the larger the total volume of snow released by all avalanches (Fig. 5).

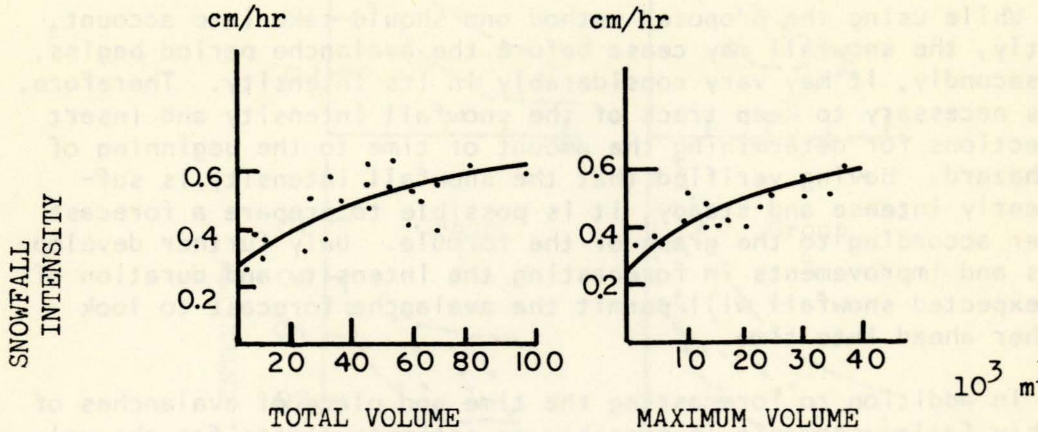


Fig. 5 Intensity of snowfall versus total volume of snow released by all avalanches and maximum volume released in a single avalanche.

Limiting curves may be constructed for peak volume and the total volume (Fig. 6).

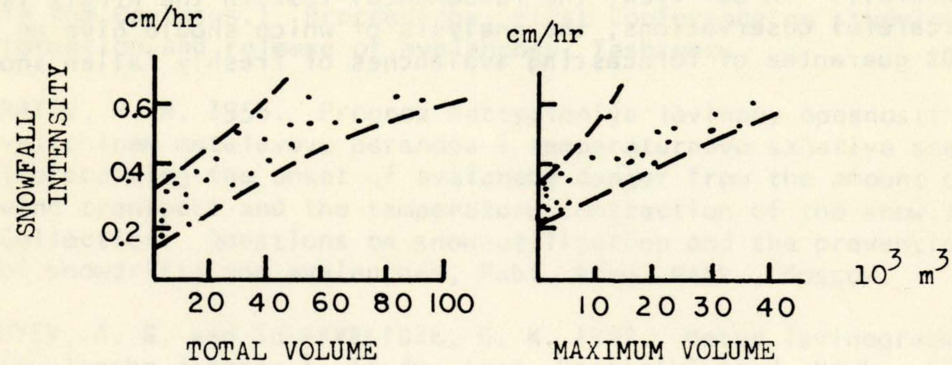


Fig. 6 Limits on the total volume of snow released by all avalanches and the maximum volume released in a single avalanche.

It should be noted that these relationships apply only to avalanches of freshly fallen snow and cannot be applied to avalanches of a mixed type even if the latter are indirectly connected with the snowfall. The volume of mixed avalanches depends on the underlying strata.

Thus, the possibility of forecasting avalanches depends on the availability of a sufficient amount of observations on the intensity of snowfall. In our view, the fundamental task in the Kirgiz is to make careful observations, the analysis of which should give an 85% to 90% guarantee of forecasting avalanches of freshly fallen snow.

LITERATURE

ABDUSHELISHVILI, K. L. and TSOMAIA, V. SH. 1963. Iz opyta prognosa skhoda lavin cvezhevypavshevo snega v gorakh Zakavkaz'ia. (On an experiment of forecasting avalanches of freshly fallen snow in the Caucasus.) Proceedings, First Conference on studying the formation and release of avalanches, Tashkent.

AKKOURATOV, V. N. 1956. Prognoz nactypleniya lavinnoy opasnosti po velichinam metelevovo perenosa i temperaturnovo szhatiya snega. (Forecasting the onset of avalanche danger from the amount of wind transport and the temperature contraction of the snow.) Collection: Questions on snow utilization and the prevention of snowdrifts and avalanches, Publ. Acad. Nauk., Moscow.

BALABUYEV, A. G. and SULAKVELIDZE, G. K. 1947. Metod lavinogramm. (Avalanche diagram.) Trudy, Inst. Geofiziki Acad. Nauk., Gruz. S.S.R., Vol. 12.

GONGADZE, D. N. 1954. Nekotorye voprosy teorii obpazobaniya i dvizheniya cnezhnykh lavin. (Several theoretical questions on the formation and movement of snow avalanches.) Trudy, Inst. Geofiziki Acad. Nauk., Gruz. S.S.R., Vol. 13, Tbilisi.

GONGADZE, D. N. 1955. Nekotopye voprosy dinamiki snezhnykh lavin. (Several questions on the dynamics of snow avalanches.) Collection: Questions on snow studies and its utilization in the national economy, Moscow.

IVERNOVA, M. I. 1953. Snezhhye obvaly v Terskey - Alatau. (Snow avalanches in the Terskey - Alatau.) In: Geographical Investigations in the central Tien-Shan, Acad. Nauk., Moscow.

IVERONOVA, M. I. 1962. Rezhim snezhnykhobvalov v Terskey - Alatau i ikh gidrologicheskoe i geomorfologicheskoe znachenie. (The snow regime in the Terskey - Alatau and its hydrological and geomorphological significance.) Trudy, Inst. Geografii Acad. Nauk. S.S.S.R., Works of the Tien-Shan physical-geographical station, Moscow.

KRASNOSEL'SKII, E. B. 1963. K voprosu opredeleniya stepeni lavinnoi opasnosti v Tsentral'non Tyan' - Shane. (On the question of determining the degree of avalanche danger in the Central Tien-Shan.) Proceedings, First Conference on studying the formation and release of avalanches, Tashkent.

LOSEV, K. S. 1960. Metody prognoza nachala perioda lavinnoi opasnosti vo vremya snegopadov i metelei. (Method of forecasting the onset of the avalanche hazard at the time of snowfall and blizzards.) Izv. Acad. Nauk. S.S.S.R., seria, geogr., No. 6.

MAKSIMOV, N. V. and KRASNOSEL'SKII, E. B. 1964. Opyt iskycctvennovo ystraneniya lavinnoi opasnosti v vysokogornykh raionakh Tyan'-Shanya. (An experiment on the artificial removal of the avalanche hazard in the high mountain regions of the Tien-Shan.) Trudy, Voeykova Central Geophysical Observatory, Vol. 1960, Gidrometizdat, Leningrad.

MOSKALEV, YU. D. 1963. Ob opredelenii granits ochagov neustoichivovo zaleganiya snega. (On determining the critical layer of weakness in a snow slab.) Proceedings, First Conference on studying the formation and release of avalanches, Tashkent.

SAATCHAN, G. G. 1936. Sneg i snezhnye obvaly. (Snow and snow avalanches.) Tbilisi.

SULAKVELIDZE, G. K. 1955. Nekotopye fizicheskie svoistva snegnovo pokrova. (Several physical properties of the snow cover.) Collection: Questions on snow studies and its utilization in the national economy, Moscow.

TUSHINSKII, G. K. 1949. Laviny. (Avalanches.) Geografgiz., Moscow.

TUSHINSKII, G. K., GUS'KOBA, E. F., and GUBAREVA, V. D. 1963. Perekristallizatsiya snega i voznikovenie lavin. (Recrystallization of the snow and formation of avalanches.) Publ. Moscow Univ., Moscow.

CHITADZE, V. S. 1961. K voprosy obraovaniya i bor'ba nimi. (Questions on the formation of avalanches and protection against them.) Trudy, Tbilisi N.I.G.M.I., Vol. 9. Gidrometizdat, Leningrad.

SHCHERBAKOV, M. P. 1962. K voprosy o fizicheskoi ovocnovannosti lavinogramm G. G. Saatchana. (On the question of the physical justification of the avalanche diagram of G. G. Saatchan.) Izv. Acad. Nauk. Kaz. S.S.R., seria energeticheskaya, Vol. 1(21).

SHCHERBAKOV, M. P. 1964. Rol' meteorologicheskikh faktorov v razvitii snezhnoi tolshchi. (The role of meteorological factors in the evolution of snow slabs.) Isv. Acad. Nauk. S.S.S.R., Seria Geogr., Vol. 2.

SHCHERBAKOV, M. P. 1965. Izmenenie velichiny stsepleniya nekotopykh vidov snega v zabisimosti ot vysoty, plotnosti i vremeni lezhaniya snezhnovo pokroba i nekotorye voprosy prognozovaniya lavin. (Change in the amount of cohesion of several snow types as a function of thickness, density, and time of deposition and several questions on forecasting avalanches.) In press at Frunze.

SHCHERBAKOV, M. P. 1966. Opyt lavinnovo paionirovaniya territorii Kirgizii. (Experience in avalanche zoning of the Kirghiz territory.) Akademiia Nauk. Kirgizskoi SSR, Frunze, Geogr. Observ., Izv. No. 6, pp 5-19.

FLAIG, W. 1955 Lawinen Abenteuer und Erfahrung. Erlebnis und Zehre, Sweite Auflage, Wiesbaden.

SELIGMAN, G. 1936. Snow structure and ski fields. London.

ZDARSKY, M. 1929 Beiträge zur Lawinenkunde. Hersg von Alpen- Skiverein, A-B-C und verl.